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Healthy and Climate-Friendly Eating Patterns in the New Zealand Context

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Background: The global food system is driving both the climate crisis and the growing burden of noncommunicable disease. International research has highlighted the climate and health co-benefit opportunity inherent in widespread uptake of plant-based diets. Nevertheless, uncertainty remains as to what constitutes healthy and climate-friendly eating patterns in specific world regions.

Objectives: Using New Zealand as a case study, this research investigates the extent to which potential contextual differences may affect the local applicability of international trends. It further examines the potential for demand-end avenues to support a transition toward a healthier, more climate-friendly food system in New Zealand.

Methods: A New Zealand-specific life-cycle assessment (LCA) database was developed by modifying cradle to point-of-sale reference emissions estimates according to the New Zealand context. This food emissions database, together with a New Zealand-specific multistate life-table model, was then used to estimate climate, health, and health system cost impacts associated with shifting current consumption to align with dietary scenarios that conform to the New Zealand dietary guidelines (NZDGs).

Results: Whole plant foods, including vegetables, fruits, legumes, and whole grains were substantially less climate-polluting ($1.2–1.8\ \mathrm{kgCO_2e/kg}$) than animal-based foods, particularly red and processed meats ($12–21\ \mathrm{kgCO_2e/kg}$). Shifting population-level consumption to align with the NZDGs would confer diet-related emissions savings of 4–42%, depending on the degree of dietary change and food waste minimization pursued. NZDG-abiding dietary scenarios, when modeled out over the lifetime of the current New Zealand population, would also confer large health gains (1.0–1.5 million quality-adjusted life-years) and health care system cost savings (NZ$14–20 billion).

Discussion: Guideline-abiding dietary scenarios, particularly those that prioritize plant-based foods, have the potential to confer substantial climate and health gains. This research shows that major contextual differences specific to New Zealand's food system do not appear to cause notable deviation from global trends, reinforcing recent international research. https://doi.org/10.1289/EHP5996

Introduction

The global food system is driving a syndemic of malnutrition and climate change (Swinburn et al. 2019). Although economic, technological, and social developments over the past century have led to significant improvements in both standard of living and life expectancy in industrialized countries (World Bank 2017a, 2017b), such developments have coincided with drastic alterations to people's lifestyles: the greater availability of both highly processed and animal-based foods, for instance, has caused a shift away from healthier and more traditional plant-based eating patterns (Chopra et al. 2002; Godfray et al. 2018; Popkin 1993; Speedy 2003). This shift has, in turn, been coupled with a dramatic rise in the rates of noncommunicable diseases, including cardiovascular disease, cancer, and diabetes [now collectively accounting for 73% of deaths globally (GBD 2017 Causes of Death Collaborators 2018)]. Indeed, suboptimal diets, which are greatly influenced by exposure to unhealthy food environments (Swinburn et al. 2019), are responsible for approximately 16% of global annual disability-adjusted life-years (DALYs) attributable to noncommunicable disease [i.e., 255 million (GBD 2017 Diet Collaborators 2019; GBD 2017 DALYs and HALE Collaborators 2018)] and one-fifth of the annual deaths worldwide, making this the single most important risk factor for mortality both globally and in New Zealand (GBD 2017 Mortality Collaborators 2018; Tobias and Turley 2016; GBD 2017 Risk Factor Collaborators 2018).

The same global economic processes that underpin the world's growing burden of chronic disease have also led to unparalleled and potentially irreversible impacts on Earth's natural systems (Steffen et al. 2015). The global food system is among the principal drivers behind this unprecedented planetary disruption, responsible for up to 29% of all anthropogenic greenhouse gas emissions (GHGs; Vermeulen et al. 2012), as well as significant soil degradation, deforestation, biodiversity loss, and nitrogen and phosphorous cycle disruption (Willett et al. 2019). Of the numerous global environmental issues that humanity must now address, climate change is considered to be one of the most challenging; it risks undermining both the public health gains of the last half-century (Watts et al. 2015) and the capacity of all nations to achieve the United Nations Sustainable Development Goals (United Nations Division for Sustainable Development 2015). The climate crisis has, in fact, been deemed this century's greatest global health threat, carrying serious implications for human health by way of extreme weather events, altered infectious disease patterns, increased food insecurity, and compromised air and drinking water quality (Costello et al. 2009).

Given the current food system's role in both the global burden of chronic, noncommunicable disease and the climate crisis, the importance of transitioning toward a healthy and more climate-friendly food system is incontestable (Willett et al. 2019). Fortunately, foods that are health-promoting, such as vegetables, fruits, legumes, and whole grains, also tend to be those that are climate-friendly (Tilman and Clark 2014). Conversely, certain foods that carry known health risks are particularly climate-polluting. For example, the production and consumption of red and processed meat is associated with increased risk of cardiovascular disease (Micha et al. 2012), type 2 diabetes (Pan et al. 2011), and certain cancers (Bouvard et al. 2015; GBD 2015 Risk Factors Collaborators 2016) while also being highly emissions-intensive. This is mainly due to the capacity of ruminant mammals to emit large quantities of methane gas, a potent, if

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short-lived, greenhouse gas (Godfray et al. 2018). Importantly, in considering food choices more broadly, even the least emissions-intensive animal foods tend to produce more GHG emissions than do healthy plant-based substitutes (Poore and Nemecek 2018).

Enabling widespread dietary change therefore has great potential to simultaneously improve health outcomes and mitigate climate change. It has been estimated, for instance, that a global transition to healthy and nutritionally adequate dietary patterns that focus on sustainable food choices could reduce premature mortality by as much as 22% and cut diet-related emissions by between 54% and 87% (Springmann et al. 2018). Moreover, research has shown that the potential of dietary change to reduce GHG emissions far exceeds what is currently achievable through altered production methods and innovative technologies (Poore and Nemecek 2018).

In light of the evidence, policymakers are increasingly being called upon to implement measures that take advantage of climate and health co-benefit opportunities associated with population-level uptake of plant-based diets, including, for instance, taxes, subsidies, labeling schemes, and other incentives (Godfray et al. 2018; Mozaffarian et al. 2012). Incorporating sustainability considerations within national dietary guidelines has been identified as an important step toward effective policy development, allowing governments to take action on nutrition-related health objectives while simultaneously addressing climate concerns: a so-called double-duty action (Gonzalez Fischer and Garnett 2016; Swinburn et al. 2019). It has also been argued that such an approach may provide individuals themselves with greater incentive to follow nutrition recommendations (USDA 2015).

As global environmental issues worsen, and the need for urgent action increases, there remains a tendency among policymakers to be parochial in their decision-making: awaiting evidence to both support the local applicability of international research and to address context-specific, and often industry-promoted, uncertainties (Noss 2010; Oreskes and Conway 2010; Swinburn et al. 2019). In this respect, New Zealand may be seen as an important case study, given that national food production systems are generally considered to be more efficient and less emissions-intensive than those in other parts of the world (Kerr 2016), despite scant evidence to support such claims (FAO 2010; Ledgard et al. 2010; Lieffering et al. 2012; Saunders et al. 2006). Central to the debate is livestock, with the majority of sustainable diet modeling studies including impacts of industrialized, grain-fed production systems, as opposed to grazing systems such as those widely used in New Zealand and elsewhere (Aleksandrowicz et al. 2016; Garnett et al. 2017). In addition, differences may exist with respect to electricity-dependent production stages for countries whose grids are largely derived from renewable sources, as is the case in New Zealand [81% (Ministry of Business Innovation and Employment 2017)]. Furthermore, transport-related emissions associated with food items imported into New Zealand, which is geographically isolated, have also been argued to differ (Howitt et al. 2011). It is widely appreciated that there is a significant shortage of environmental analyses that consider diverse food groups and production systems in different parts of the world (Clune et al. 2017). Importantly, the true extent to which international trends apply in New Zealand has not previously been described, and this has relevance to other countries with claims to major contextual differences in terms of farming practices, energy production, and geography.

In order to address these literature gaps, this research had three principal aims: first, to build a more nuanced picture of climate-friendly diets by examining the degree to which contextual differences may cause a deviation from international trends, using New Zealand as a case study; second, to understand the potential for demand-end avenues to support a transition toward a healthier and more climate-friendly food system in New Zealand; and third, to provide impetus for policy action by helping to resolve persisting uncertainties surrounding food-related emissions in the New Zealand context.

These aims were met through the development of a New Zealand-specific food emissions database, estimation of daily diet-related emissions associated with the typical New Zealand diet, and subsequent modeling of climate, health, and health system cost impacts associated with a range of dietary scenarios that conform to the New Zealand dietary guidelines (NZDGs) (McIntyre and Dutton 2015).

Methods

New Zealand Food Emissions Database Assembly

The internationally standardized method for analyzing the environmental impacts of different commodities, known as life-cycle assessment (LCA), considers emissions arising from all production and, where possible, consumption and disposal processes for any given food item (Finkbeiner et al. 2006). Assembly of an LCA database of foods and their associated GHG emissions is considered to be an essential step in comparing the climate impacts of individual food items, and of dietary patterns overall (Heller et al. 2013). In order to inform the assembly of a New Zealand-specific database, we undertook a broad search of both the peer-reviewed and gray literature that aimed to identify extant New Zealand-specific LCAs as well as database assembly and dietary modeling methods. (For search details, see Box S1, "Search Strategy" and Box S2, "Inclusion and Exclusion Criteria," in the Supplemental Material, and Figure S1.) Although our search identified a number of New Zealand-specific LCA studies covering a range of food items commonly consumed in New Zealand (see Excel Table S1), it did not provide a sufficient degree of diversity to allow for traditional database compilation. Furthermore, the dietary modeling studies and extant LCA databases identified within our search provided no guidance for developing a database in the context of limited country-specific data. We therefore opted to use an existing LCA database so as to provide baseline emissions estimates that could then be modified according to the New Zealand context. In selecting a database that could most effectively function as a reference, we ranked all databases identified within our initial search according to predetermined essential and nonessential criteria. Criteria were based on LCA principles outlined in the most recent International Organization for Standardization (ISO) standard [i.e., system boundary breadth, methodological transparency, and clearly defined functional unit (Finkbeiner et al. 2006)] as well as on specific database qualities that would support modification according to the New Zealand context [i.e., the manner of LCA breakdown, diversity of food items, methodological homogeneity, geographical specificity, publication date, and uncertainty reporting (further details regarding our criteria are available in Table S1)]. Of the seven LCA databases identified within our review (Audsley et al. 2009; Berners-Lee et al. 2012; Clune et al. 2017; Hoolohan et al. 2013; Scarborough et al. 2014; Tilman and Clark 2014; Wickramasinghe et al. 2016), the database of Hoolohan et al. (2013) was the only one to meet both essential criteria (see Table S2 for the results of the ranking process). The database of Hoolohan et al. (2013), which provides per-kilogram cradle to point-of-sale emissions estimates for 66 food categories in the UK, including the relative contributions of seven life cycle stages (farming and processing, transportation, transit packaging, consumer packaging, warehouse and distribution, refrigeration, and supermarket overheads), was therefore selected as our reference database. Food intake data used within this study, covering 346 individual food groups, were acquired directly from the research group responsible for conducting the New Zealand Adult Nutrition Survey [University of Otago's Life in New Zealand Research Group; T. Blakely (personal communication)]. The New Zealand Adult Nutrition Survey (NZANS) was a multiple-pass, 24-h diet recall survey of 4,721 New Zealanders ≥ 15 years of age that was conducted in 2008–2009 and commissioned by the New Zealand Ministry of Health (Parnell 2011). Each NZANS food group was matched to a food category within the reference LCA database (Hoolohan et al. 2013) (see Excel Table S2), and reference emissions estimates [in the form of kilograms of carbon dioxide equivalents per kilogram of product ($kgCO_2e/kg$) with the global warming potential of each component gas measured on a 100-y time horizon] were assigned accordingly. In instances where NZANS food items could not be adequately matched to a Hoolohan et al. (2013) category, emissions estimates for those NZANS food items were either assigned from a secondary LCA source (unmatched raw; $n = 17$) or estimated from a standard online recipe (by combining estimates for component ingredients in their relative proportions in line with the approach taken by Scarborough et al. (2014); unmatched composite; $n = 45$), depending on whether they comprised a single or multiple ingredients. (Secondary sources for unmatched raw items and recipes for unmatched composite items are available in Excel Tables S3 and S4, respectively.)

Reference emissions estimates for each of the 346 NZANS food groups were then modified according to the New Zealand context, with efforts concentrated on life cycle stages that contributed most to overall emissions (i.e., farming and processing), as well as those where the New Zealand context was expected to differ most from the Hoolohan et al. (2013) reference database (emissions stemming from both transportation and electricity usage). Food Balance Sheets were used to assess the quantity of each food group that is produced in New Zealand versus that imported from abroad (FAOSTAT 2013b). For domestically produced food groups, New Zealand-specific emissions estimates, where available, were used to represent the farming and processing stage (i.e., they replaced equivalent reference estimates). (See Excel Table S1 for details regarding available New Zealand-specific LCA studies and Excel Table S5 for details regarding the selection of representative estimates where multiple studies were available.)

Where New Zealand-specific LCAs were not available for domestically produced food groups, a proxy farming and processing emissions estimate was assigned based on an average of New Zealand-specific values from similar food items, as has been done elsewhere (Audsley et al. 2009; Berners-Lee et al. 2012; Hoolohan et al. 2013). If a proxy estimate could not be assigned, the reference database value was used and assumed to be equivalent, in line with the approach taken by Wilson et al. (2013). As a specific exception to the above, where New Zealand-specific emissions estimates were unavailable for certain dairy products, proxy values were calculated by scaling the New Zealand-specific emissions estimate for milk according to multipliers used to account for density differences (i.e., the quantity of milk required to produce each milk product) within the reference Hoolohan et al. (2013) LCA database (see Equation S1 in the Supplemental Material). It was assumed that the processing of milk into other dairy products requires the same relative inputs in New Zealand as in the reference database country (UK). Food groups exclusively imported into New Zealand do not require the consideration of New Zealand-specific farming and processing emissions estimates, and contributions from this phase were assumed to be the same as the reference database. For food groups partially produced in New Zealand and partially imported, New Zealand-specific emissions estimates, where available, were combined with values from the reference database, according to the ratio of quantity produced to quantity imported.

Reference transportation estimates were replaced with New Zealand-specific estimates that were calculated by estimating the distances that food groups travel and then multiplying these distances by emissions factors (average per kilometer emissions associated with transporting one gram of food) for the respective modes of transport. The specific emissions factors used within this study, which include indirect emissions arising from fuel supply chains and those embodied in vehicles themselves, were taken from the reference database (Hoolohan et al. 2013). All New Zealand-produced foods were ascribed the same transportation footprint ($0.13\ kgCO_2e/kg$), based on prior work that estimated the average road distance between farm and coastal port in New Zealand (Saunders and Zellman 2007). For food groups imported into New Zealand, main trading partners were identified and ranked according to their contribution to total imports using 2013 FAO Detailed Trade Matrix data (FAOSTAT 2013a). Because most food groups are sourced from numerous countries, international transportation emissions associated with the highest-ranking countries were sequentially incorporated into calculations for each group until at least 80% of total imports had been accounted for, or a maximum of six countries were included. Final transportation estimates were weighted according to each county's percent contribution to total imports, and calculations included the following: land transportation between the primary production location and the nearest major port; mode of international transport; port-to-port distance; and domestic land transportation within New Zealand. Finally, the associated transportation emissions of food items that are both produced in and imported into New Zealand were estimated by calculating emissions for domestically produced foods and imported foods, and then producing a final weighted estimate according to the ratio of quantity produced to quantity imported (see Equation S2 in the Supplemental Material).

Potential differences in electricity-related emissions were accounted for by scaling the electricity component of downstream life cycle stages (warehouse and distribution, refrigeration, and overheads), according to differences in nonrenewable electricity usage between New Zealand and the UK (Department of Energy and Climate Change 2014; Ministry of Business Innovation and Employment 2017). Other emissions sources from these life cycle stages (including refrigerant gas leakage; staff commuting; business travel; water, oil, and gas usage; and supermarket office consumables) have been shown to contribute minimally to the overall diet footprint in the UK (Berners-Lee et al. 2012), and were considered to be generalizable to the New Zealand context. Emissions associated with food packaging in New Zealand were also assumed to be equivalent to estimates included within the reference database, based on the fact that specific food products are typically packaged using similar amounts of the same materials (Saunders et al. 2006).

Having adjusted reference emissions estimates from individual life cycle stages according to important New Zealand differences, the per-kilogram, cradle to point-of-sale emissions for the 346 food groups within our database were calculated. In order to compare both long- and short-term climate impacts of individual food groups and overall dietary patterns, we also converted emissions estimates for methane-intensive food items from the conventional global warming potential measured on a 100-y time horizon (GWP_{100}) to a 20-y time horizon (GWP_{20}); it has been argued that using a single timeframe is arbitrary and risks overlooking either the near-term impacts of methane or the long-lasting warming effects of carbon dioxide (Balcombe et al. 2018; IPCC 2014a). Given that beef, lamb, dairy products, and rice are the principal contributors to agricultural methane emissions [~ 80–90% (Scheehle and Kruger 2006)], GWP conversion calculations were performed for these select items and all products containing them ($n = 77$), using GWPs from the most recent

Table 1. Descriptions of modeled dietary scenarios (DG1–DG10) that conform to the New Zealand dietary guidelines.

Scenario name (code)	Description
New Zealand Dietary Guidelines (DG1)	Shifts current consumption with minimum necessary change to meet the New Zealand Ministry of Health's (NZMOH) Eating and Activity Guidelines for New Zealand Adults (NZDGs). This involved increasing intake of the vegetables (by 170%[a]); fruits (245%[a]); legumes, nuts, and seeds (145%[a]); whole grains (320%[a]); fish and other seafood (145%[a]); and milk and products categories (170%) while significantly reducing intake of highly processed foods (by 75%); drinks and foods with added sugar (by 90%); processed meats (by 72%), and refined grains (by 50%), according to NZDG daily serving recommendations. Individual food items within respective NZDG categories were scaled in proportion to amounts consumed at baseline according to the NZANS intake data. Additional scaling was performed for the grains category so that three-quarters of intake was from whole grain sources, as per advice from the NZMOH officials. Butter was also replaced with margarine, whereas coconut oil and animal lard were replaced with plant oils, according to NZDG guidance on minimizing saturated fat intake.
Once weekly plant-based meal (DG2)	Meeting NZDGs (DG1) plus one serving from the NZDG meat, seafood, and egg category replaced once weekly with two servings from the NZDG legumes, nuts, and seeds category in accordance with NZDG guidance on consuming at least one serving of meat, seafood, or eggs or two servings of legumes, nuts, and seeds per day. Individual food items within respective categories were scaled in proportion to amounts consumed at baseline.
Beef and lamb replaced with poultry and pork (DG3)	Meeting NZDGs (DG1) plus: *a*) remaining processed meat reduced to zero with servings redistributed proportionally among other discretionary categories (i.e., foods with added sugar and highly processed foods) and *b*) red meat (beef and lamb) replaced, in terms of energy (kJ), with poultry and pork. Individual food items belonging to the poultry and pork groups were scaled up in proportion to baseline consumption.
Meat exchanged for seafood, eggs, legumes, nuts, seeds: pescatarian (DG4)	Meeting NZDGs (DG1) plus: *a*) remaining processed meat reduced to zero with servings redistributed proportionally among other discretionary categories (i.e., foods with added sugar and highly processed foods) and *b*) meat (lamb, beef, chicken, pork, other meat) replaced, in terms of energy (kJ), with other forms of nondairy protein (eggs, fish, legumes, nuts, and seeds) according to baseline consumption.
Once daily plant-based meal (DG5)	Meeting NZDGs (DG1) plus one serving from the NZDG meat, seafood, and egg category replaced once daily with two servings from the NZDG legumes, nuts, and seeds category in accordance with NZDG guidance on consuming at least one serving of meat, seafood, or eggs or two servings of legumes, nuts, and seeds per day. Individual food items within respective categories were scaled in proportion to amounts consumed at baseline.
Meat and seafood exchanged for eggs, legumes, nuts, seeds: lacto-ovo vegetarian (DG6)	Meeting NZDGs (DG1) plus: *a*) remaining processed meat reduced to zero with servings redistributed proportionally among other discretionary categories (i.e., foods with added sugar and highly processed foods) and *b*) meat and seafood replaced, in terms of energy (kJ), with other forms of nondairy protein (eggs, legumes, nuts, and seeds), according to baseline consumption.
Beef and lamb replaced with legumes, nuts, and seeds (DG7)	Meeting NZDGs (DG1) plus: *a*) remaining processed meat reduced to zero with servings redistributed proportionally among other discretionary categories (i.e., foods with added sugar and highly processed foods) and *b*) red meat (beef and lamb) replaced, in terms of energy (kJ), with legumes, nuts, and seeds. Individual food items belonging to the legumes, nuts, and seeds groups were scaled up in proportion to baseline consumption.
Meat, seafood, eggs exchanged for legumes, nuts, seeds: lacto-vegetarian (DG8)	Meeting NZDGs (DG1) plus: *a*) remaining processed meat reduced to zero with servings redistributed proportionally among other discretionary categories (i.e., foods with added sugar and highly processed foods) and *b*) meat, seafood, and eggs replaced, in terms of energy (kJ), with other legumes, nuts, and seeds, according to baseline consumption.
Meat, seafood, eggs, and dairy replaced with plant-based alternatives: vegan (DG9)	As per DG8, plus recommended daily servings of the NZDG milk and products category met through plant sources only (soy milk and soy yogurt), which were increased in proportion to DG1 consumption.
Waste-free vegan (DG10)	As per DG9, plus elimination of avoidable food waste.

[a]Energy losses resulting from each dietary scenario were fully compensated for by proportionally increasing intake of five food groups [vegetables and fruit; legumes, nuts, and seeds; whole and less processed foods (whole grains); and seafood] in accordance with NZDG-recommended dietary changes for New Zealand adults. Therefore, the percent increases for these five food groups reported for scenario DG1 include both the change required to meet the NZDGs and the change required to compensate for energy losses. In scenarios that involved the elimination of seafood, we did not use seafood for energy compensation. A sensitivity analysis was also conducted using 75% energy compensation.

Intergovernmental Panel on Climate Change assessment report (IPCC 2014b). Individual LCA studies that did not specify which GWPs were used in their emissions calculations were assumed to have followed the most recent IPCC values at the time of their publication. Emissions estimates for food items that are not considered to be methane-intensive were assumed to be the same on a 100-y horizon as on a 20-y horizon.

New Zealand Dietary Guideline Scenarios

Ten dietary scenarios (DG1–DG10) that conformed to the NZDGs were developed (Table 1). In ensuring that each scenario adhered to NZDG recommendations (McIntyre and Dutton 2015), we consulted with the New Zealand Ministry of Health to clarify qualitative statements used within their guidelines (e.g., mostly, in reference to whole grains, and limit, in reference to a number of discretionary items, including processed meats). Each food item within our emissions database was assigned the most appropriate serving size from the examples provided within the guidelines (see Excel Table S2 for serving sizes). The average number of daily servings consumed from each NZDG food group at baseline, based on average daily gram intake data from the NZANS, was then compared with the number of daily servings required to meet the parameters of each dietary scenario (DG1–DG10); intake was then scaled in proportion to baseline consumption. As a consequence of the significant reduction in discretionary food intake required to meet the NZDGs, a reduction in total daily energy intake was expected. Given that there is no explicit recommendation within the NZDGs to reduce total energy intake, energy losses associated with each dietary scenario were fully compensated for by scaling up consumption of five food groups in accordance with NZDG recommendations [vegetables; fruits; legumes, nuts, and seeds; whole and less processed foods (whole grains); and seafood]. In doing so, modeled scenarios were standardized to a 2,130 kcal diet, in line with average reported daily caloric intake according to the NZANS. Such an approach is consistent with other similar studies (Hoolohan et al. 2013; Scarborough et al. 2014), allowing relative climate impacts of different food groups in the diet to be more clearly demonstrated, without energy intake confounding results (Aleksandrowicz et al. 2016). Nevertheless, research suggests that energy compensation following dietary interventions is incomplete (Stubbs et al. 1998), particularly when the intervention involves reducing sugary sweetened beverage intake (Reid et al. 2007) although considerable uncertainty remains regarding the degree to which energy compensation occurs. In order to consider what impact decreases in energy intake might have on diet-related emissions, we also conducted a sensitivity analysis whereby energy losses within each scenario were only partly compensated for [75%; based on the upper limit of energy compensation tested by Grieger et al. (2017)].

Dietary Modeling

Climate–impact modeling. The average New Zealand adult's daily diet-related emissions (in kilograms carbon dioxide equivalents per day) were calculated by multiplying the average daily gram intake of each food group included in the NZANS by its respective emissions estimate from our New Zealand-specific database. Avoidable food waste emissions (i.e., those associated with food that is discarded unnecessarily or allowed to expire prior to consumption) were incorporated into calculations using UK data (Quested and Murphy 2014) and assuming that patterns of food waste among those living in the UK are representative of those living in New Zealand. The overall impact on diet-related emissions associated with shifting current consumption to meet each scenario (DG1–DG10) was then calculated. Sensitivity analyses were conducted using GWP_{20} emissions estimates and incomplete (75%) energy compensation. In the absence of either uncertainty estimates within the LCA studies our database comprised, or a reliable source of proxy estimates, uncertainty within our database was set at a uniform 20% (the upper uncertainty limit used within the multistate life-table model described in the following section) for all foods.

Health–impact modeling. An established multistate life-table (MSLT) model (Cleghorn et al. 2019a, 2019b) was used to estimate the difference in quality-adjusted life-years (QALYs) and health care system costs in 2011 New Zealand dollars (NZ\$2011) between the current New Zealand adult's diet and each theoretical dietary scenario (DG1–DG10). The New Zealand population in 2011 ($n = 4.4$ million) was modeled out to death or until age 110 in the MSLT model. The model is parameterized with rich national data by sex, age, and ethnicity. The MSLT model included a range of dietary risk factors (including high intake of red meat, processed meat, sugar-sweetened beverages, and sodium as well as low intake of fruit, vegetables, and polyunsaturated fat) and 17 diseases associated with one or more dietary risks: coronary heart disease, stroke, type 2 diabetes, osteoarthritis, and multiple cancers (endometrial, kidney, liver, esophageal, pancreatic, thyroid, colorectal, breast, ovarian, gallbladder, head and neck, and lung and stomach). All disease input parameters were specified by sex, age, and ethnicity unless stated otherwise (see Table S3).

For each dietary scenario (DG1–DG10), we estimated changes in intake of fruit, vegetables, red meat, processed meat, sugar-sweetened beverages, sodium and in the percentage of total energy from polyunsaturated fat intake, compared with current dietary patterns. The changes in these dietary risk factors were combined with disease-specific relative risks obtained from the Global Burden of Disease (GBD) study (GBD 2013 Risk Factors Collaborators et al. 2015) through population impact fractions that alter the incidence within diet-related disease life-tables. Time lags between changes in dietary risk factors and disease incidence were modeled to account for the time lags in disease etiology. For example, changes in coronary heart disease incidence in each year of the simulation reflected the average dietary exposures over the preceding 5 y (for further details, see Cleghorn et al. 2017).

Overall morbidity was calculated as the years of life lived with disability (YLDs) from the New Zealand Burden of Disease Study (NZBDS; McIntyre and Dutton 2013) divided by the population count, by sex, age, and ethnicity. Disease-specific morbidity was calculated as the total comorbidity-adjusted YLDs for that disease divided by the prevalent population. These disability weights were derived from the GBD study using pairwise comparisons from multicountry surveys (Salomon et al. 2012).

Health system costs associated with incidence, prevalence, and death from each of the modeled diseases, and for individuals without disease, were estimated according to a specific protocol (Kvizhinadze et al. 2016), and the values for costs are provided in the MSLT model technical report (Cleghorn et al. 2017). Cost savings were determined from the difference in projected future health system expenditure due to alterations in disease incidence (resulting from changes in dietary risk factors) and overall life expectancy.

A discount rate of 3% was applied to the health impact and health care system cost results. Given that the interventions were theoretical scenarios, we did not include any financial costs relating to dietary changes. The model was run in Microsoft Excel using an Ersatz add-in (Ersatz, version 1.3; EpiGear International). Monte Carlo analysis was used to estimate uncertainty intervals for each result, with 2,000 simulations run for each scenario.

Results are presented with and without adjusting for differences in background mortality and morbidity by ethnicity: a partial assessment of the equity impact of the scenarios examined. Performing an equity analysis is important, given significant differences in background mortality and morbidity rates between different ethnic groups in New Zealand, particularly between Māori (New Zealand's indigenous peoples) and non-Māori. The equity analysis set the all-cause mortality and population morbidity rates for Māori to those currently experienced by non-Māori to avoid undervaluing health gains for Māori (McLeod et al. 2014).

Finally, we examined the sensitivity of results to the assumption of no change in energy intake by conducting a sensitivity analysis where energy losses associated with meeting the NZDGs (DG1) were only partly, instead of fully, compensated for (75%). The reduction in total energy intake resulted in a proportional decrease in body mass index, based on estimates of weight change following reductions in energy intake reported by Hall et al. (2011).

Results

New Zealand Food Emissions Database

Modified reference emissions estimates varied substantially between different foods (Figure 1). As a general rule, the climate impact of animal-based foods in New Zealand was considerably higher than that of plant-based foods. When comparing commonly consumed food items, beef and lamb were by far the greatest contributors to climate change: emitting 21 and 17 $kgCO_2e$, respectively. These values are lower than global averages (median 27 $kgCO_2e/kg$ and 26 $kgCO_2e/kg$ for beef and lamb, respectively), with New Zealand estimates falling just within the first quartile of international estimates (Clune et al. 2017). Other meats—including processed meats (12 $kgCO_2e/kg$), pork (11 $kgCO_2e/kg$), and shellfish (ranging between 11 and 43 $kgCO_2e/kg$), along with butter (11 $kgCO_2e/kg$), and cheese (10 $kgCO_2e/kg$)—were also found to carry large climate impacts, primarily due to the feed inputs required to produce nonruminant animal foods and the fuel use required to harvest seafood. Most other animal-based foods, including fish (5.9 $kgCO_2e/kg$), eggs (4.9 $kgCO_2e/kg$), poultry (3.9 $kgCO_2e/kg$), and yogurt (3.3 $kgCO_2e/kg$), fell within the 2–10 $kgCO_2e/kg$ range. Highly processed foods (including cookies, cakes, muffins, puddings, pies, pastries, and ice cream) and foods high in added sugar (such as confectionary and sugar-sweetened beverages) fell, on average, within the 2–4 $kgCO_2e/kg$ range. The majority of plant foods—including legumes (1.5 $kgCO_2e/kg$), vegetables (1.8 $kgCO_2e/kg$), fruits (1.2 $kgCO_2e/kg$), grains (1.4 $kgCO_2e/kg$), and cereals (1.8 $kgCO_2e/kg$)—along with milk and milk alternatives, were

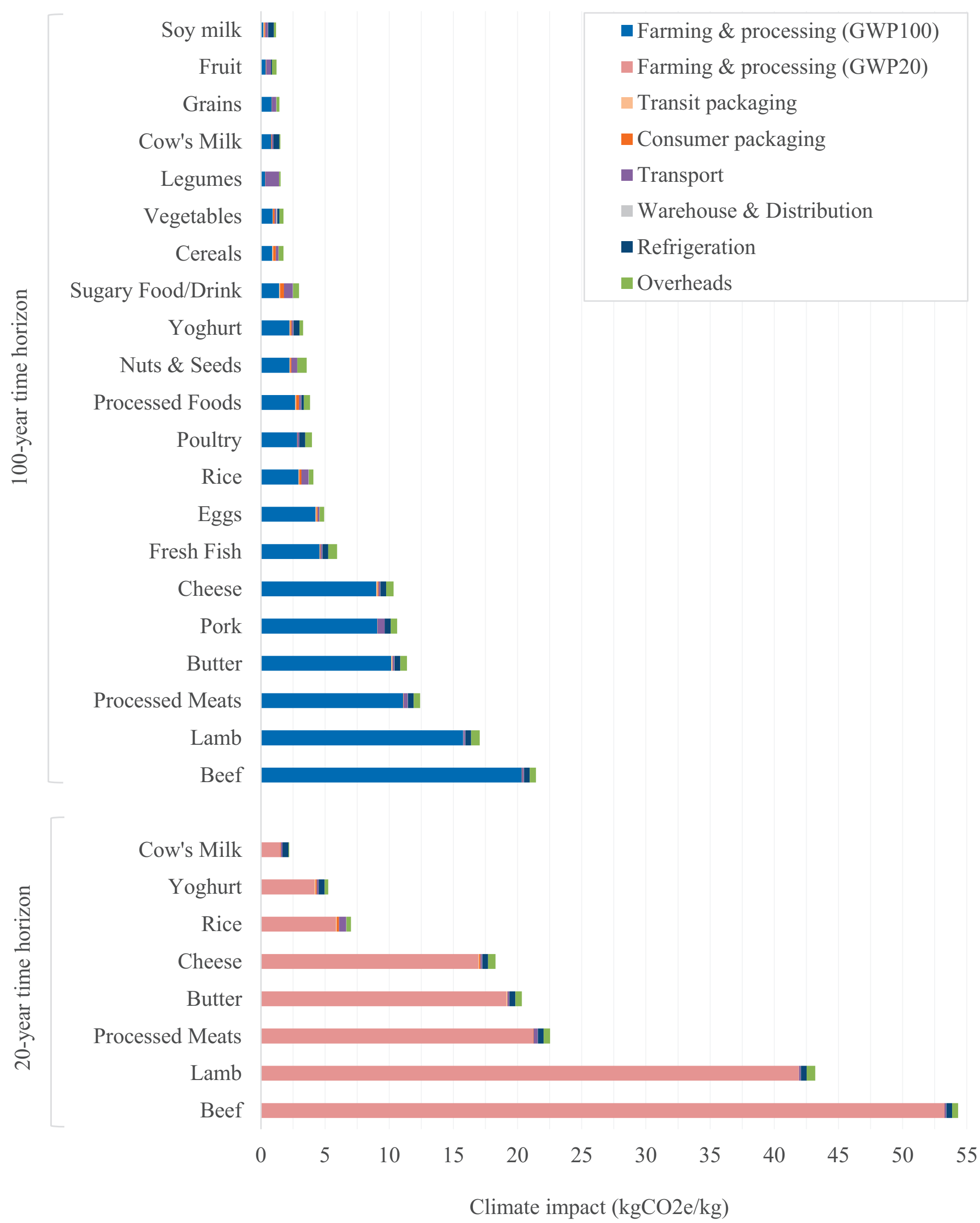

Figure 1. Climate impact of commonly consumed food items in New Zealand disaggregated by life cycle stage, with a comparison of 100-y and 20-y horizons for methane-intensive items. See Excel Table S6 for details of the complete New Zealand-specific Food Emissions Database. CO_2e, carbon dioxide equivalents; GWP100, global warming potential measured on a 100-y time horizon; GWP20, global warming potential measured on a 20-y time horizon.

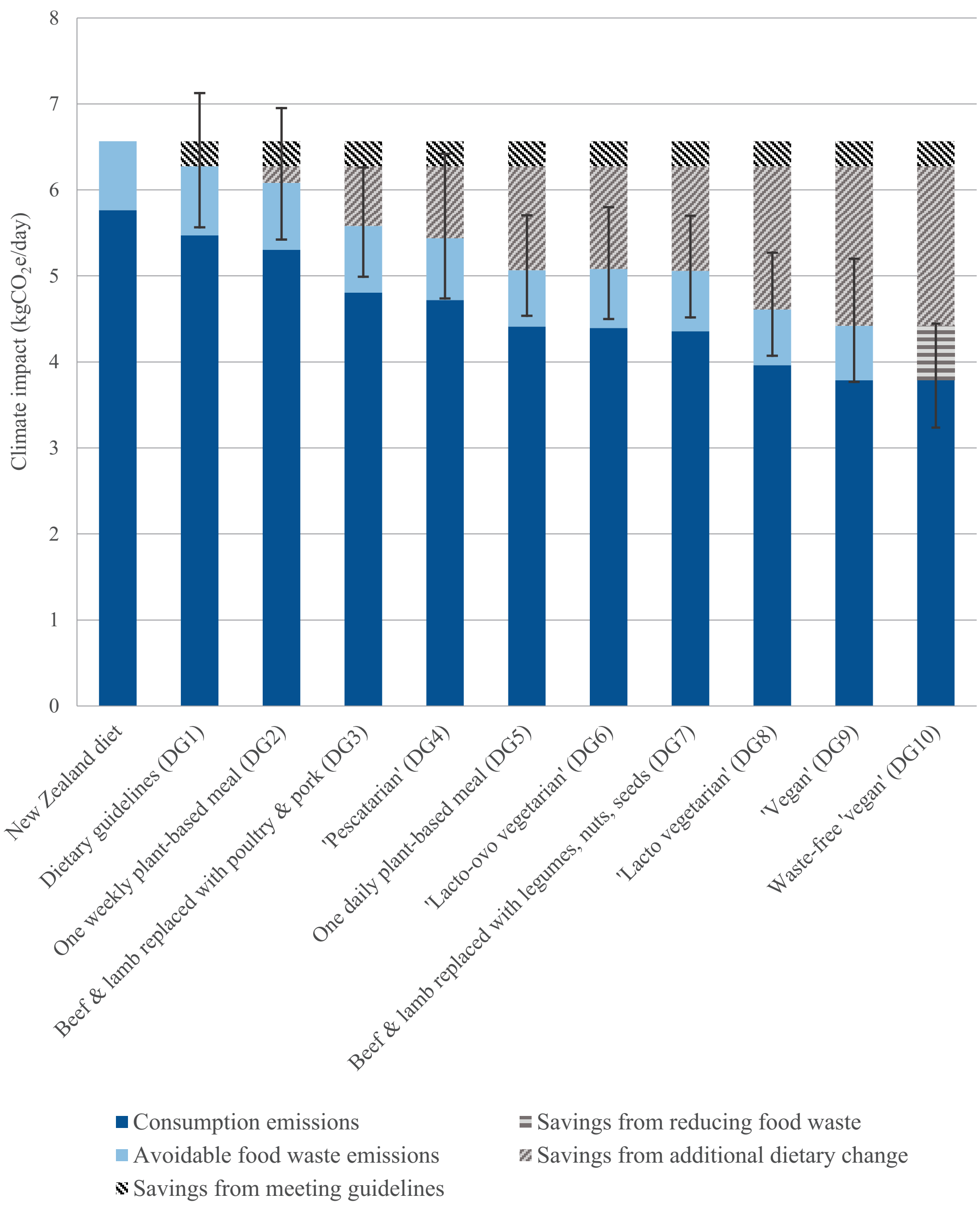

Figure 2. Climate impact of dietary scenarios (DG1–DG10) as compared with the typical New Zealand diet. Detailed descriptions of scenarios DG1–DG10 can be found in Table 1. Scenarios DG2–DG10 include the minimum change required to meet New Zealand dietary guidelines (DG1). Error bars: 95% uncertainty intervals. CO_2e, carbon dioxide equivalents.

associated with $<2\,kgCO_2e/kg$. Two important exceptions include rice ($4.1\,kgCO_2e/kg$) and the nuts, seeds, and dried fruit category ($3.6\,kgCO_2e/kg$).

Time horizon conversion calculations for select methane-intensive food items resulted in significantly increased emissions estimates (Figure 1). Compared with a 100-y time horizon, estimates for both beef and lamb increased 250% when measured on a 20-y time horizon (to 54 and $43\,kgCO_2e/kg$, respectively). Rice increased 170% (to $7\,kgCO_2e/kg$), whereas milk and other dairy product emissions increased between 140% and 270%.

The farming and processing stage of production contributed the most to variation across food items, as well as to each individual food item's emissions. Transport-related emissions contributed minimally to the overall impact of most food items in New Zealand. The complete New Zealand-specific database, including all 346 food groups, is provided in Excel Table S6.

Dietary Modeling

Climate–impact modeling. Daily diet-related emissions associated with the typical New Zealand adult's diet were found to equate to $6.6\,kgCO_2e$, with over a third (35%) coming from meat, seafood, and egg consumption and a further quarter (24%) from highly processed foods. Avoidable food waste contributed $0.8\,kgCO_2e$ toward daily diet-related emissions (12%), with approximately one-quarter of these emissions arising from both wasted vegetables (24%) and wasted meat, seafood, and eggs (23%). Regarding the relative impacts of the various life cycle stages, farming and processing contributed over two-thirds (68%) of average diet-related emissions, whereas transportation, packaging, and refrigeration (contributing 9%, 6%, and 5%, respectively) collectively accounted for only one-fifth. In combining our estimate of the average New Zealand adult's diet-related emissions with the latest adult population estimates [3.9 million ≥15 years of age (Statistics New

Zealand 2018)], we calculated that annual emissions associated with the New Zealand diet equate to 9.2 $MtCO_2e/y$. After removal of GHG emissions embodied within foods produced outside of the country (1.9 $MtCO_2e$), diet-related emissions in New Zealand were found to be approximately equivalent to 9.4% of the country's total annual emissions (Ministry for the Environment 2019). These numbers are certainly underestimates given that they do not include emissions associated with the diets of the nearly 1 million New Zealanders who are <15 years of age.

Shifting current consumption to meet the NZDGs, while having made the minimum required change to the average New Zealand adult's eating pattern (DG1), resulted in modest diet-related GHG savings of 4% or 0.29 $kgCO_2e/d$ [−0.07 to 0.70; 95% uncertainty interval (UI)]. Such GHG savings were mainly attributed to the significant reduction (72%) in processed meat intake required to meet the NZDGs. The remaining modeled dietary scenarios (DG2–DG10), which required further dietary change above and beyond the minimum needed to meet the NZDGs (DG1), all led to an increasing level of diet-related GHG savings. Figure 2 shows the climate impact of all scenarios, including the additional impact of reducing avoidable food waste. One weekly serving of meat, seafood, and eggs replaced with legumes, nuts, and seeds (DG2) conferred an additional GHG savings of 3% beyond meeting the NZDGs (7% in total); if this was done once daily (DG5), additional savings would amount to 18% (23% in total). Replacing all meat, seafood, and eggs with legumes, nuts, and seeds (DG8) extended additional savings to 25% (30% in total), whereas a vegan scenario (DG9), which also replaced dairy products with plant-based alternatives, offered the greatest additional savings at 28% (33% in total). If avoidable household food waste was eliminated, additional savings of between 10% and 12% could be achieved, depending on the scenario. For instance, total diet-related emissions savings afforded by the vegan scenario could be increased from 33% to 42% with the elimination of avoidable food waste [total savings of 2.78 $kgCO_2e/d$ (1.98 to 3.72; UI) DG10].

Incorporating emissions estimates based on 20-y GWPs resulted in large changes to baseline consumption emissions and potential GHG savings from all scenarios (see Table S4). The average New Zealand adult's current diet-related emissions were 140% greater when GWPs of component gases were measured on a 20-y time horizon, as compared with a 100-y horizon (6.6–9.4 $kgCO_2e/d$), whereas percent GHG savings conferred across the various NZDG scenarios were increased by between 130% and 210%. For instance, we found that simply meeting the NZDGs (i.e., minimum required dietary change; DG1) would confer 9% emissions savings for the average New Zealand adult, as compared with 4% on a 100-y horizon. At the more ambitious end of the spectrum, we estimated that the waste-free vegan scenario (DG10) could reduce the average New Zealand adult's diet-related emissions by as much as 58% on a 20-y time horizon, compared with 42% on a 100-y horizon.

The mitigation potential of all scenarios was increased when energy losses associated with dietary change were not fully compensated for (see Table S4). For example, diet-related emissions savings associated with meeting the NZDGs (DG1) were increased from 4% to 7%, when compensating for 75% of lost energy instead of 100% (net energy loss of 86 kcal/d). Furthermore, emissions savings associated with a vegan-type scenario (DG9) were increased from 33% to 35% (net energy loss of 92 kcal/d). These calorie losses are approximately equivalent to estimated changes in caloric intake over the previous 20 y (Fallah-Fini et al. 2019). This suggests that realistic decreases in caloric intake offer only a small benefit in terms of emissions savings, especially when compared with the potential of shifting food choices.

Health–impact modeling. All dietary scenarios (DG1–DG10) required substantial increases in daily fruit and vegetable intake (130–214 g and 108–231 g, respectively), increased daily intake of nuts and seeds (ranging from 1 to 50 g), decreased daily sugar-sweetened beverage intake (nearly −100 mL), decreased daily processed meat intake (ranging from −47 to −56 g), decreased daily sodium intake (ranging from −0.09 to −0.35 g), and increased daily polyunsaturated fat intake (ranging from 0.5% to 5.5% of total energy). To meet the dietary guidelines with minimal required change (DG1), a reduction in red meat intake was not required, but in all other scenarios (DG2–DG10) daily red meat intake was decreased by 5–52 g. Dietary risk factor changes associated with shifting average consumption to meet each scenario are presented in Table S5.

Shifting the typical New Zealand adult's diet to meet the dietary guidelines conferred large health benefits [1.02 million QALYs (0.82–1.25 million; 95% UI)] and cost savings to the health system [NZ$13.9 billion (NZ$10.5–18.0 billion; 95% UI); DG1; Table 2] over the lifetime of the cohort. Beyond meeting the NZDGs, replacing one weekly serving of meat, seafood, and eggs with legumes, nuts, and seeds (DG2) increased baseline health gains and cost savings to 1.21 million QALYs and NZ$17.0 billion, respectively; if this was done once daily (DG5), we estimate that savings would amount to 1.31 million QALYs and NZ$18.6 billion. Replacing beef and lamb with plant-based alternatives (legumes, nuts, and seeds; DG7) provided 1.35 million QALYs and NZ$19.1 billion cost savings. The lacto-vegetarian scenario (DG8), where all meat, seafood, and eggs were replaced with legumes, nuts, and seeds, increased health gains to

Table 2. Health gain {in mean quality-adjusted life-years [uncertainty interval (UI)]} and health system costs saved (UI) from shifting current consumption to meet each dietary scenario (DG1–DG10) among the New Zealand adult population alive in 2011 (3% discounting).

	Total population	
Scenario name (code)	QALYs for remainder of the cohort's life (millions)	Health system cost savings for remainder of the cohort's life [2011NZ$ (billions)]
New Zealand dietary guidelines (DG1)	1.02 (0.82, 1.25)	13.9 (10.5, 18.0)
Once weekly plant-based meal (DG2)	1.21 (0.97, 1.48)	17.0 (12.9, 21.9)
Beef and lamb replaced with poultry and pork (DG3)	1.18 (0.95, 1.42)	16.8 (12.7, 21.4)
Meat exchanged for seafood, eggs, legumes, nuts, seeds: pescatarian (DG4)	1.16 (0.94, 1.44)	16.6 (12.4, 21.5)
Once daily plant-based meal (DG5)	1.31 (1.06, 1.57)	18.6 (14.1, 24.2)
Meat and seafood exchanged for eggs, legumes, nuts, seeds: lacto-ovo vegetarian (DG6)	1.38 (1.10, 1.68)	19.5 (14.7, 24.6)
Beef and lamb replaced with legumes, nuts, and seeds (DG7)	1.35 (1.07, 1.65)	19.1 (14.4, 24.8)
Meat, seafood, eggs, exchanged for legumes, nuts, seeds: lacto-vegetarian (DG8)	1.42 (1.14, 1.72)	19.9 (14.8, 26)
Meat, seafood, eggs and dairy replaced with plant-based alternatives: vegan (DG9)	1.46 (1.17, 1.77)	20.2 (15.3, 26.2)
Waste-free vegan (DG10)	1.46 (1.17, 1.77)	20.2 (15.3, 26.2)

Note: Detailed descriptions of scenarios DG1–DG10 can be found in Table 1. Scenarios DG2–10 include minimum change(s) required to meet New Zealand dietary guidelines (i.e., DG1).

1.42 million QALYs and cost savings to NZ$19.9 billion. Vegan scenarios (DG9 and DG10) conferred the greatest health gains and costs savings: 43% more QALYs (1.46 million in total) and 45% greater cost savings (NZ$20.2 billion in total) than meeting the dietary guidelines alone (DG1).

Larger health gains were seen in men than in women across all dietary scenarios; health gains were more than double for men meeting the dietary guidelines as compared with women (DG1; see Table S6). When applying either crude or age-standardized ratios, per capita health gains among Māori were found to be between 70% and 103% greater than those found among non-Māori, depending on the scenario. When an equity analysis was applied, per capita health gains among Māori were found to be between 121% and 178% greater than those found among non-Māori. These added gains are the result of a combination of factors, including different baseline dietary patterns (Cleghorn et al. 2017), different disease rates (BODE3 2019), and differences in relative risks of disease by age and sex (Cleghorn et al. 2017).

Finally, health gains and health care cost savings resulting from meeting the NZDGs with minimal change (DG1) increased by 0.37 million QALYs and NZ$7.4 billion, respectively, when energy losses were only partly (75%), as opposed to fully, compensated for (net energy loss of 86 kcal/d).

Discussion

Main Findings

Life cycle emissions were found to vary considerably between different foods in New Zealand. As a general rule, the climate impact of animal-based foods tended to be substantially higher than that of plant-based foods. Meat products, particularly beef and lamb, were among those associated with the highest GHG emissions. Such variation was primarily due to differences in the farming and processing stage of production and was greatly accentuated when emissions estimates were calculated on a 20-y, as opposed to a 100-y, time horizon. New Zealand food item emissions tended to align closely with the international literature, and although slight differences in emissions estimates for individual foods may be present, general trends regarding how foods compare with one another hold true (Clune et al. 2017; Tilman and Clark 2014).

The typical New Zealand adult's daily diet-related emissions were found to be 6.6 $kgCO_2e$. Although no other New Zealand-specific, LCA-based estimate of diet-related emissions was found to exist at the time of writing, this is broadly in line with estimates from around Europe, including France (Vieux et al. 2012), Germany (Meier and Christen 2013), Denmark (Saxe et al. 2013), Finland (Risku-Norja et al. 2009), and the UK (Hoolohan et al. 2013; Scarborough et al. 2014), which range from 4.1 to 8.8 $kgCO_2e$. Making direct comparisons between countries, however, is difficult given the appreciable differences in both how GHG databases are compiled and how dietary intake data are collected.

Depending on the degree of dietary change pursued among New Zealand adults at the population level, as well as the extent to which avoidable food waste is minimized, we calculated that diet-related emissions reductions of 4–42%, health gains of 1.02–1.46 million QALYs, and health system cost savings of NZ$13.9–20.2 billion could be achieved while meeting NZDGs. As our modeled dietary scenarios became increasingly climate-friendly, we found that associated population-level health gains and cost savings also tended to increase; an eating pattern that replaced all meat, seafood, eggs, and milk products with plant-based alternatives and that also eliminated avoidable food waste (DG10) was found to confer the greatest benefit across all three parameters.

These findings are consistent with those reported elsewhere: A recent systematic review of similar studies identified 16 scenarios that had optimized GHG savings by modeling additional dietary changes above and beyond meeting healthy eating guidelines and found a median reduction of 27% (8–51%, range) as compared with current average consumption (Aleksandrowicz et al. 2016). Our analysis showed that the potential for achieving diet-related emissions reductions is primarily determined by the type and quantity of meat consumed and that, as animal-based food intake decreases, so too do GHG emissions: a finding that supports conclusions drawn by Aleksandrowicz et al. (2016) as well as a number of other large analyses and systematic reviews of sustainable dietary modeling studies (Hallström et al. 2015; Joyce et al. 2014; Nelson et al. 2016; Springmann et al. 2018).

A combination of healthy dietary change and food waste minimization is one of the most important ways that individuals can reduce their personal climate footprint (a potential savings of 1.0 tCO_2e/y were found to be possible). Such a strategy holds great potential to contribute substantially to domestic mitigation efforts: When emissions associated with foods produced outside of New Zealand were excluded from our analysis, national annual emissions savings of up to 4.6 $MtCO_2e$ (DG10) were possible via population-wide change among New Zealand adults [$\geq$15 years of age (Statistics New Zealand 2018)]. Such a decrease would equate, for example, to one-fifth of the current emissions reductions needed to meet New Zealand's commitment under the Paris Climate Agreement [i.e., 30% below 2005 levels by 2030 (Ministry for the Environment 2019; UNFCCC 2016)], or to a 59% reduction in New Zealand's annual light passenger vehicle emissions (Ministry of Transport 2017).

Regarding the health impacts of different sustainable dietary patterns, only seven studies within the review by Aleksandrowicz et al. (2016) reported health-related outcomes, all of which showed reduced risk of either all-cause mortality or mortality from heart disease, diabetes, or colorectal cancer. Of those seven studies identified, only one investigated the health and climate impacts of different dietary patterns that conformed to healthy eating guidelines and found that doing so could prevent more than 7.5 million years of life lost (YLL) due to premature death in the UK over a 30-y period and reduce diet-related emissions by 40% while maintaining likely acceptability of the eating pattern (Milner et al. 2015). The health gains and health system cost savings associated with our NZDG scenarios (DG1–DG10) are many times larger than those resulting from specific intervention options that have previously been modeled using the same methods. A cap on single-serve sugar-sweetened beverages, for example, conferred 84,900 QALY savings and NZ$1.7 billion in cost savings (Cleghorn et al. 2019a), whereas a salt substitution intervention (59% of sodium salts being replaced with potassium and other salts in all processed food) resulted in 294,000 QALY gains and NZ$1.5 billion in cost savings (Nghiem et al. 2016). This shows there is considerable opportunity for further improvements in dietary patterns beyond what could be achieved with specific targeted intervention options that have been scoped to date. The next step will be to establish what changes in policy and practice could achieve the dietary guidelines scenarios that we have modeled here.

Limitations

The main limitation of this study is its necessary reliance on UK data. Although all domestically produced food items included within our food emissions database would ideally have been accompanied by a New Zealand-specific LCA, none was available for approximately 60% of New Zealand-produced food items. This lack of country-specific LCA literature has been acknowledged by other studies investigating the climate impacts of different dietary scenarios (Bertoluci et al. 2016; Clune et al. 2017), including the only previous New Zealand study published on this topic to date (Wilson et al. 2013). UK data were also relied upon for transportation emissions factors as well as for food waste data. Given that transportation's contribution to diet-related emissions is relatively small, however, trip-specific emissions factors would be expected to have little bearing on the overall climate impact of the New Zealand diet. Conversely, a lack of New Zealand-specific food waste data could potentially have affected emissions estimates to a greater extent: Results from New Zealand's first National Food Waste Audit suggest that less household food waste is generated in New Zealand compared with the UK, although the authors acknowledge that this may be due to methodological differences (Waste Not Consulting 2015). Unfortunately, the New Zealand audit does not report on the proportion of food purchases that tend to be wasted, and we were therefore unable to incorporate this data within our dietary modeling.

A further limitation lies in the known underreporting within dietary surveys (Becker and Welten 2001; Gemming and Ni Mhurchu 2016; Rennie et al. 2007). Because no measurement of the metabolic requirements of study participants was undertaken within the NZANS, it was not possible to adjust reported energy intake to reflect participants' energy requirements.

Despite being the most recent comprehensive national survey of dietary intake among New Zealand adults, the 2008–2009 NZANS, which provided consumption data for this study, is now a decade old. Dietary patterns, and therefore the balance of food intake of specific food groups, are likely to have shifted over this time. According to OECD data, per capita beef and lamb consumption in New Zealand has fallen by 34% and 28%, respectively, since 2009, whereas consumption of less emissions-intensive meats, such as pork and poultry, have increased (19% and 40%, respectively) over the same period (OECD-FAO 2019). This suggests that diet-related emissions within this study may have been overestimated. More recent consumption data would have improved the reliability of our estimates.

Furthermore, considerable uncertainty remains regarding the degree to which energy compensation occurs following dietary intervention in a real-world setting (Dhurandhar et al. 2015). Previous research has suggested that reducing population-level average energy intake would likely improve both health and environmental outcomes (Edwards and Roberts 2009). Our sensitivity analysis has indicated that additional emissions savings, as well as substantially greater health gains and health system cost savings, might be possible if energy losses associated with NZDG scenarios were not fully compensated for by New Zealand adults.

A lack of uncertainty reporting continues to be a limitation of individual LCA studies and, by extension, the databases that are compiled from them (Hallström et al. 2015). Although emissions estimates for any given food item are known to differ (Clune et al. 2017), determining the extent to which variability (i.e., true differences resulting from distinct production systems and geographical contexts) and uncertainty contribute to such discrepancies remains problematic (Notarnicola et al. 2017). It is possible that the uncertainty applied within this analysis (a uniform 20%) has underestimated the true uncertainty inherent within our emissions estimates. Nevertheless, due to the magnitude of difference, in terms of climate impact, that has been shown to exist between select food items, a number of studies have emphasized the need to focus on general trends when comparing food items rather on numerical emissions values themselves (Clune et al. 2017; Röös et al. 2010).

Implications

Relatively few food emissions databases utilizing a bottom-up LCA approach have been compiled. To the best of our knowledge, this is the first country-specific LCA database to be compiled outside of Europe and North America, and it sets a general method for other countries to follow suit. Furthermore, only a handful of studies have assessed the climate and health impacts of meeting healthy eating guidelines. Our findings reinforce that substantial emissions savings and health gains are possible via population-level uptake of guideline-abiding eating patterns, particularly those that prioritize plant-based foods. By analyzing the health care system costs associated with such dietary change and providing evidence that large cost savings are possible, this research offers an economic incentive for policymakers to enable change.

This research has further demonstrated that major contextual differences specific to New Zealand's food system (i.e., a grazing-based livestock production system, relative geographical isolation from the world's major food exporters, and an electricity grid that is largely derived from renewable sources) do not appear to cause notable deviation from global trends. Importantly, the stark contrast between plant and animal protein sources in terms of climate impact, which is described repeatedly within the international literature, is no less relevant in New Zealand, and overshadows any differences in emissions associated with meat production between countries. If, for instance, the emissions estimates for New Zealand beef and lamb were in line with global averages taken from Clune et al. (2017), we estimated that eliminating consumption of ruminant meats in the context of our most climate-friendly NZDG scenario (DG10) would only increase associated diet-related emissions savings from 42% to 46%.

We argue that these findings should prompt national policy action, including the incorporation of climate considerations within New Zealand's dietary guidelines, and that other important measures, such as pricing strategies, labeling schemes, and climate-friendly food procurement guidelines, should also be implemented. We further assert that such policies should be contextualized to meet the specific social, cultural, and economic needs of various populations.

This research also has important implications for other countries where uncertainty persists surrounding the local applicability of international best evidence relating to healthy and climate-friendly eating patterns. Irrespective of the setting or food system in question, policies that enable a transition toward diets that are predominantly plant-based appear likely to confer substantial climate and health co-benefits. Our findings reinforce the message from the recent EAT-*Lancet* Commission that the global evidence base is sufficiently strong to justify urgent action among policymakers, and that further postponement poses a great risk to society (Willett et al. 2019).

Furthermore, we are not aware of another study that has explored the impact that measuring global warming potentials of component GHGs over a 20-y period has on diet-related emissions. We foresee near-term temperature effects becoming increasingly relevant as global average temperature rise approaches 1.5°C: The historical focus on a 100-y metric has discouraged mitigation strategies relating to potent but short-lived climate pollutants such as methane, which may provide a crucial buffer in stabilizing temperatures while decarbonization of the global community occurs (Scovronick et al. 2015). There is a growing need for similar data focusing on near-term impacts so as to adequately inform policy decisions relating to both climate mitigation and adaption strategies.

Future Research

Using our food emissions database, New Zealand researchers will now be able to assess the climate impacts of potential dietary interventions (e.g., a tax on sugar-sweetened beverages, a saturated fat tax, or a fruit and vegetable subsidy), alongside both health and health system cost parameters. Such information is likely to provide additional leverage for instituting policy change. Incorporation of other environmental parameters (such as land, water, and biodiversity impacts) within LCA databases such as ours should also be seen as an important priority. Beyond the accumulation of further evidence to support policy action, research efforts that focus on addressing systemic barriers to change—including opposition from powerful food industry groups and the reluctance of policymakers to institute evidence-based, regulatory solutions—should be prioritized (Swinburn 2019).

Conclusion

This research has characterized healthy and climate-friendly food choices and eating patterns in the New Zealand context and demonstrates that local trends are not dissimilar from those found globally. This has important implications for other countries where uncertainty remains regarding the applicability of international evidence. Eating patterns emphasizing the consumption of whole, plant-based foods offer an opportunity to achieve substantial emissions reductions while simultaneously realizing considerable health gains and health system cost savings. Well-designed public policy is needed worldwide to support the creation of a global food system that no longer exacerbates the climate crisis nor the burden of noncommunicable disease.

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